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DISINFECTING 200,000,000 GALLONS OF WATER A DAY—EXPERIENCE WITH CHLORIDE OF LIME AND LIQUID CHLORINE AT TORRESDALE FILTRATION PLANT

By Francis D. West

In a paper presented before the annual convention of the New England Water Works Association, September 10, 1913 ("Torresdale Filter Plant Methods and Results 1907–1913" by Francis D. West, Chemist in charge Torresdale Laboratory and Joseph S. V. Siddons, Superintendent Torresdale Filters, (*Journal N. E. W. W. A.*, vol. 27, no. 3, September, 1913), a general summary of the results obtained with the use of calcium hypochlorite was given.

The following article goes into detail and includes the results obtained with liquid chlorine November 26, 1913, to date; together with certain data on liquid chlorine gathered from other sources.

Historical Sketch of Disinfection at Torresdale

ELECTROLYTIC SODIUM HYPOCHLORITE

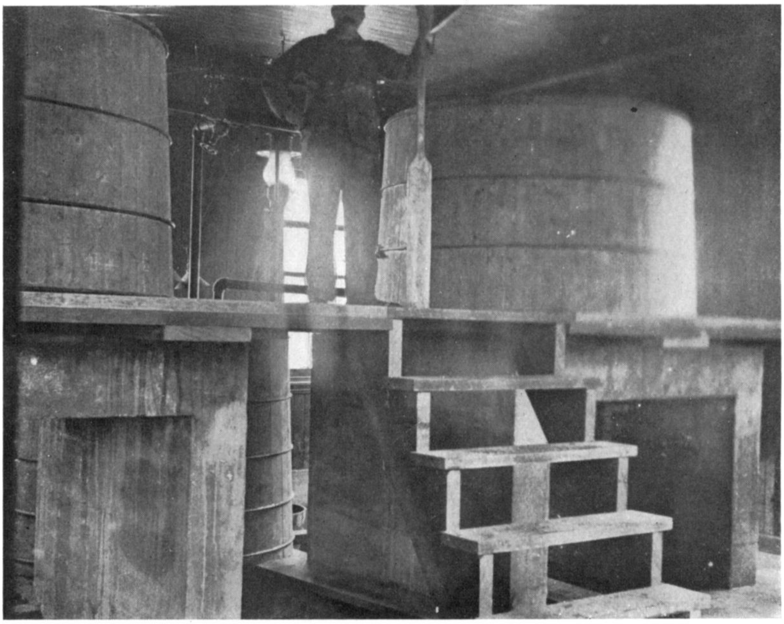
Bleach was first used at Torresdale in the form of hypochlorite of soda produced electrolytically during September, 1909.

Two cells were used. A current of 35 amperes at 110 volts was used to decompose a brine solution. The chlorine and soda were allowed to recombine and the temperature was so high (about 110° F.) that chlorates were formed. The bleach was applied directly in front of the inlet valve of one of the preliminary filters operated at a 20 M. G. P. D. rate or about one-fourth normal.

The conclusions were in part that the bacterial efficiency of the filter was considerably less than that of filters operated at four times the rate without treatment.

CALCIUM HYPOCHLORITE

Hypochlorite was again used in December, 1910. Due to the fact that the bacterial efficiency of slow sand filters decreases considerably in cold weather and the fæcal organism B. Coli Communis was present in the filtered water, it was decided to use chloride of lime to disinfect the water in the filtered water basin.



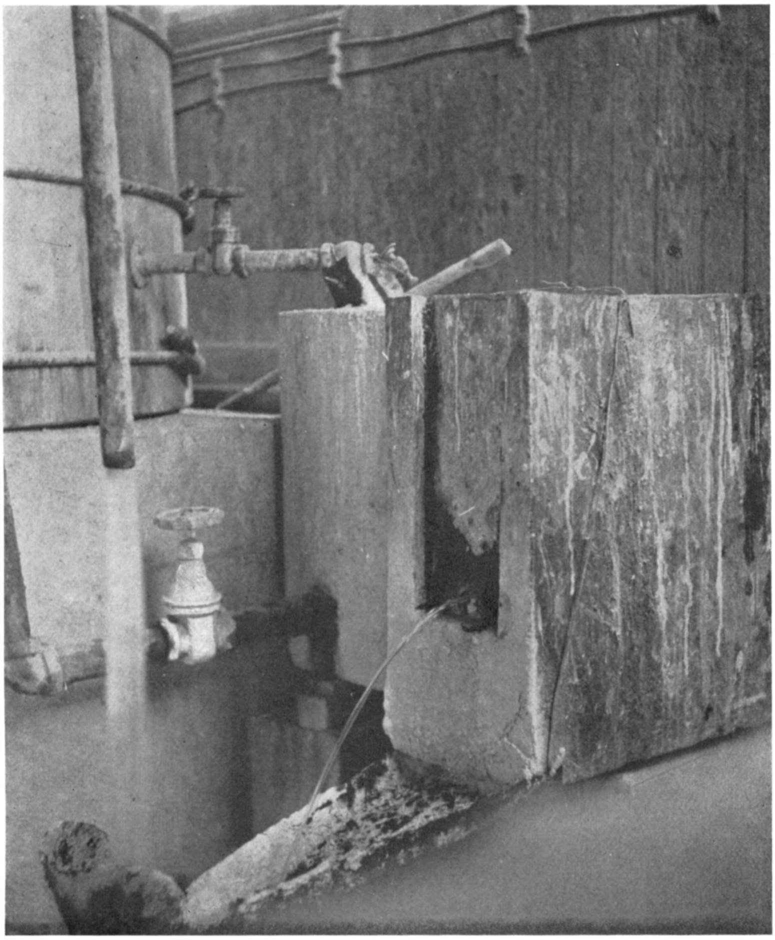
No. 1. Torresdale Hypochlorite Plant Mixing and Solution Tanks

Treatment was continued until April, 1911, when it was stopped until December. Treatment was again started December, 1911, and was continued without interruption until February, 1913.

LIQUID CHLORINE

This was first used November 26, 1913, in conjunction with chloride of lime, about 90 pounds liquid and 800 pounds powder being used daily until February 9, when the use of chloride of lime was stopped.

Description of bleach plant. The plant at first consisted of two cedar mixing tanks each 5 feet in diameter and 4 feet deep and one solution tank of the same dimensions, capacity about 500 gallons; and a yellow pine orifice tank cubical in shape, 2 feet on a side. This tank was soon changed to a concrete tank of the same dimensions. After five months' continuous use the tanks became so badly perforated that they could no longer be used. They were replaced by new tanks which were later lined with 3 inches of cement. The capacity was reduced to 380 gallons.



No. 2. Torresdale Hypochlorite Plant Orifice Tank

Cut No. 1 shows the mixing and solution tanks and cut No. 2 shows the orifice tank.

Mixing. This was done by hand by two laborers using paddles, each mix receiving about two hours agitation.

Cost. The cost of installation of the chloride of lime plant amounted to $815 (this does not include the tanks purchased later) and the cost of operation for the first five months was 9 cents per million gallons.

The cost for 1912 was 9 cents and for 1913 11 cents per million gallons.

No charge is allowed for time of sample collector or services of chemist.

From two to six mixes were made a day, usually three, using 500 and later 380 gallons of water per mix.

Analytical tests. Tests were made of samples of powder, of solution and of sludge, giving a close check on how well the bleach was mixed.

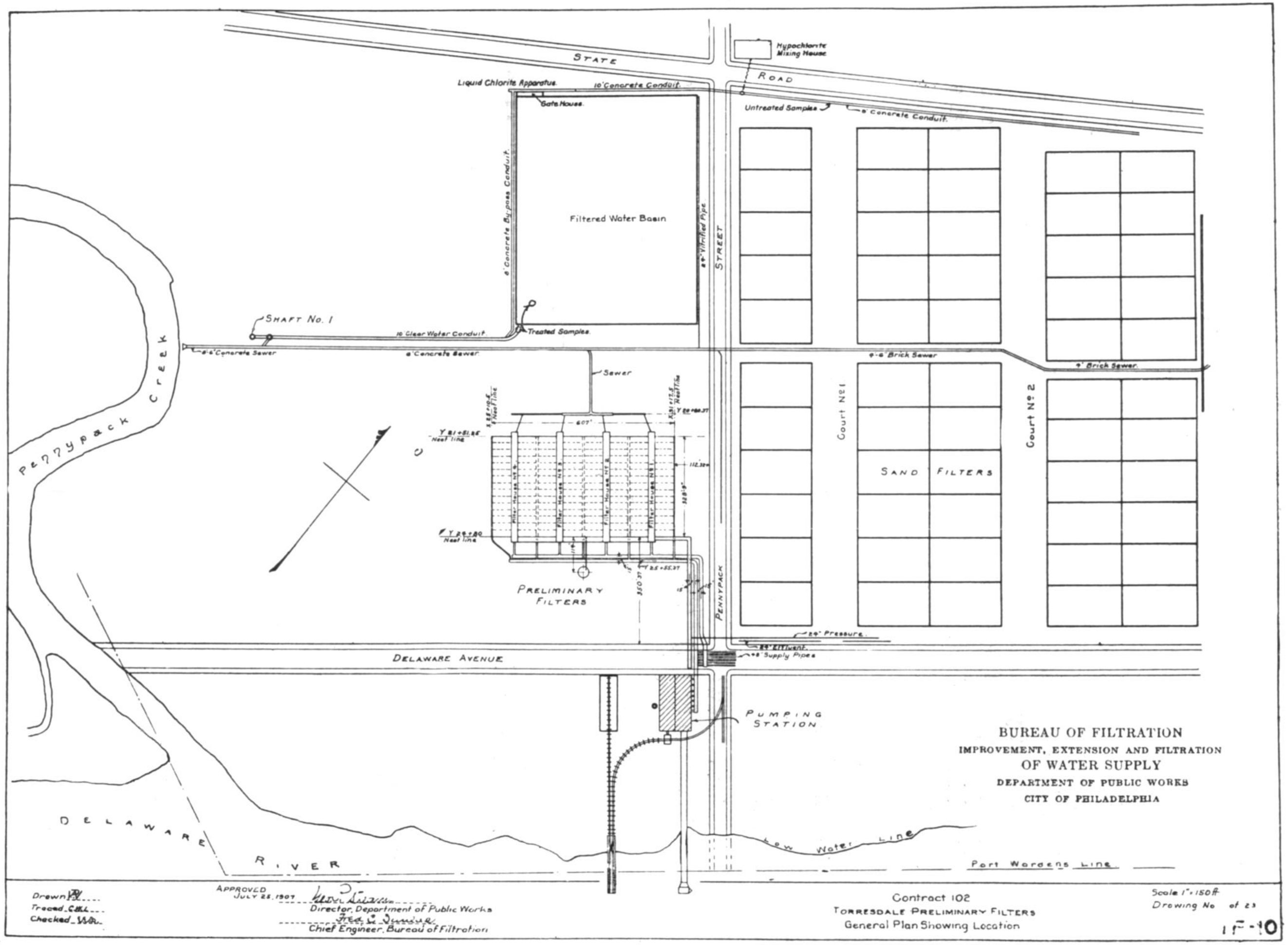
Table I shows the quantities of powder and strength of solutions used at different periods. The maximum amount was 3480 pounds per day and the minimum 420 pounds.

TABLE I

A	B	C	D	E	F	G
420	36.0	151	10.1	3.6	0.28	0.10
540		194	13.0	4.7	0.36	0.13
600		216	14.4	5.2	0.40	0.14
800		288	19.2	6.9	0.53	0.19
1,200		433	28.9	10.4	0.80	0.29
1,600		577			1.07	0.38
2,000		720			1.33	0.48
2,400		864			1.60	0.58
3,200		1,154			2.13	0.77
3,480		1,255			2.32	0.84

A = pounds powder per day.
B = Average available chlorine in bleach.
C = Pounds available chlorine per day.
D = Per cent of powder in solution tank at 500 gallons.
E = Per cent available chlorine in solution tank.
F = Parts per million powder in filtered water basin at 180,000,000 gallons per day.
G = Parts per millions available chlorine in ditto.

The amount of available chlorine wasted in sludge has varied from 0.1 to 7 per cent and averaged about 1 per cent.



No. 3. PLAN OF TORRESDALE FILTER PLANT SHOWING LOCATION OF HYPOCHLORITE AND LIQUID CHLORINE PLANTS

Location of bleach plant. This plant is located between the slow sand filters and the filtered water basin. The solution was fed into an air vent in the filtered water conduit. The water at this point has a velocity of 4–5 sec. ft. (See plan of Torresdale Filter Plant for location of Bleach House.)

Owing to the location of the plant and the velocity of the water it was impossible to get a sample of the combined effluents of the filters before treatment and as a consequence we have been unable to tell exactly how much work the hypo has been doing. (Recently, January 19, 1914, we made a vent in the filtered water conduit and placed in it a 4-inch pipe into which we lower our collecting device to get samples of filtered, untreated water.)

The following table (II) shows the results of treatment.

Note. Tap at Lardner's Point pumping station shows the condition of the water after passing through a 3-mile conduit 100 feet under ground.

By examining the results for May–November, 1911, it will be seen that the average number of bacteria in the filtered water basin during this period was but 35 per cubic centimeter. (Omitting November it was only 19.) The per cent of positive tests in summer was very high. In July for 10 cc. with a count of 9, 48 per cent were positive, and for June with 14 bacteria 51 per cent were positive. During November, due to temperature changes the bacteria efficiency decreased materially and the basin had an average of 120 with B. coli present in 1 cc. 13 days out of 30.

The effect of starting treatment in December is very noticeable. The use of $\frac{1}{2}$ to 1 part per million of powder, while it did not keep the count low during the spring of 1912 did nearly eliminate B. coli from the water that had passed the filters. The low count and lack of sufficient bleach caused the department to use $\frac{1}{4}$ to $\frac{1}{3}$ part of powder during the summer and as a consequence the per cent of positive tests in 10 cc. again went up reaching 34 per cent with a count of 13 in June and 26 per cent with a count of only 7 in August.

During 1913 $\frac{1}{2}$ part or more of powder was used all year and as a consequence the per cent of positive tests for the basin was but 1.4 for 1 cc. and 8.5 for 10 cc.

DISADVANTAGES OF CHLORIDE OF LIME

There are several objections to the use of hypochlorite of calcium and to our method of applying it.

TABLE II

Showing average bacteria count and number of positive tests for B. Coli Communis in Torresdale filtered water basin and tap at Lardner's Point pumping station 1911–1913 inclusive

	FILTERED WATER BASIN				LARDNER'S POINT PUMPING STATION			
MONTH	Number tests	Aver. bact. per cc.	B. Coli		Number tests	Aver. bact. per cc.	B. Coli	
			1 cc.	10 cc.			1 cc.	10 cc.
1911								
January	31	25	1	5	26	20	1	2
February	28	11	4	4	23	12	1	1
March	31	7	1	2	27	7	0	3
April	30	10	0	1	24	12	0	3
May	31	14	1	12	26	11	1	10
June	30	29	2	14	26	24	3	8
July	31	9	3	15	25	20	0	8
August	31	14	3	16	27	14	1	12
September	30	29	3	20	25	21	2	13
October	31	20	6	22	26	20	2	17
November	30	120	13	24	24	98	9	19
December	31	15	0	8	24	13	1	6
Total	365	0	37	143	303	0	21	102
Average		25				23		
Per cent positive			10.1	39.2			6.9	33.7
Jan.-April and Dec.	151	14	6	20	124	13	3	15
Per cent positive			4	13.3			2.4	12.4
May-Nov. inc	214	35	31	123	179	30	18	87
Per cent positive			14.5	58			10	48.6

January-April and December treated; May-November untreated.

TABLE II—Continued

MONTH	FILTERED WATER BASIN				LARDNER'S POINT PUMPING STATION			
	Number tests	Aver. bact. per cc.	B. Coli		Number tests	Aver. bact. per cc.	B. Coli	
			1 cc.	10 cc.			1 cc.	10 cc.
1912								
January	31	30	1	2	26	21	0	1
February	29	250	1	7	23	98	1	3
March	31	99	1	6	25	110	0	4
April	30	22	0	3	25	20	0	1
May	31	17	1	2	26	14	0	3
June	29	13	2	10	24	19	1	9
July	31	7	2	5	26	8	1	4
August	31	7	0	8	26	6	0	2
September	30	10	2	10	24	8	1	6
October	31	15	2	10	27	13	1	5
November	29	17	1	12	23	22	0	9
December	31	15	2	5	25	19	1	3
Total	364		15	80	300		6	50
Average		44				30		
Per cent positive			4.1	22			2	16.9
Per cent positive when more ½ P. was used			2.5	14.9			1.1	9.1
1913								
January	31	23	1	5	26	20	1	4
February	28	6	0	0	22	5	0	1
March	31	11	1	1	24	9	0	0

1913								
April	30	10	0	0	26	9	0	1
May	31	5	0	0	26	4	0	0
June	30	5	0	0	25	4	0	0
July	31	4	0	2	26	5	0	4
August	31	6	0	3	26	9	1	5
September	30	5	1	7	25	6	1	10
October	31	13	1	7	27	14	0	5
November	30	31	1	4	23	30	0	5
December	31	30	0	8	31	17	0	0
Total	365		5	31	301		3	35
Average		13				11		
Per cent positive			1.4	8.5			1	11.6

First: Variation in strength of solution. This is due chiefly to three things:

(a) The quantity of available chlorine in the powder has varied from 21 per cent to 43 per cent.

(b) The readiness with which the bleach mixes with water.

The writer has seen two batches of equal strength, one of which mixed readily with little sludge and the other forming lumps seemingly impossible to break up.

(c) Hand mixing of 400 pounds in 388 gallons of water.

It is not reasonable to expect that this can be done thoroughly by hand. In fact the tanks are allowed to stand for different periods of time and the one in contact with water longest has the greatest strength.

Second: Interruption to feed of solution. This may be caused, as happened, by one of three things:

(a) Corroding of orifice, decreasing the amount of flow;

(b) Stopping of orifice by lumps of sludge, and

(c) Choking up of delivery pipe.

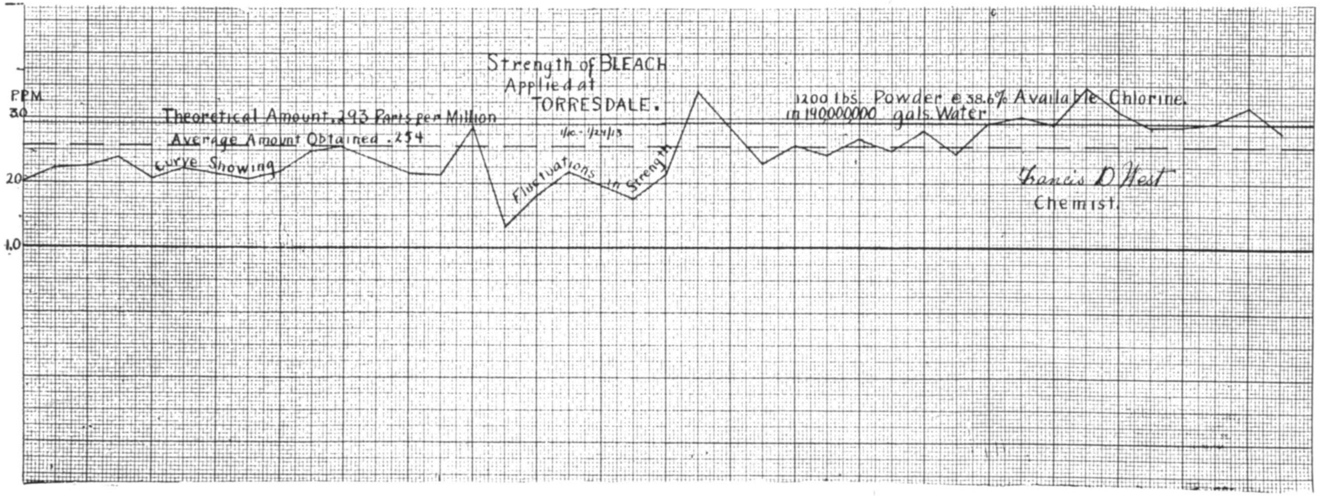
Third. Tastes and Odors. This has been in all probability the most serious objection of any at other places although we did not have many complaints. When we used over 2400 pounds per day some complaints were made.

The chart shows the variation in strength of solution from a lot of bleach which had apparently a consistent amount of available chlorine.

It also shows how much below the theoretical amount was the quantity actually obtained from the powder.

Under the most advantageous conditions we were able to get but an average of .25 parts per million out of a theoretical amount of .293 parts or only 87 per cent of what we should have gotten.

Allowing then a general average of 36 per cent of available chlorine in the powder we obtained but 31 per cent. This was with cans which were used as soon as opened. When a can is allowed to stand exposed even for a day a material loss takes place. A figure of 30 per cent available chlorine is then a high estimate of the amount gotten out of powder in practice; ordinarily with careless mixing, with no tests of powder or solutions and after exposure for days as usually happens 25 per cent may be stated as the amount the average operator will add to the water.



No. 4. Chart Showing Variation in Strength of Solution of Bleach

In considering the Chart it may be noted that .6 per cent chlorine was thrown away in sludge.

The following table (III) shows the amounts of chloride of lime used during 1912 and 1913.

TABLE III

Monthly averages available chlorine in powder

MONTH	PER CENT OF AVAILABLE CHLORINE	
	1912	1913
January	35.1	37.4
February	37.0	40.6
March	37.2	39.1
April	36.5	36.3
May	33.3	38.1
June	32.3	34.3
July	34.2	37.0
August	30.8	31.9
September	37.4	33.9
October	37.4	36.3
November	34.4	34.2
December	36.3	35.3
Annual average	35.2	36.2

TABLE III (a)

Monthly average parts per million powder and available chlorine used during 1913

MONTH	POWDER	CHLORINE
January	0.82	0.30
February	0.76	0.27
March	0.84	0.30
April	0.79	0.28
May	1.30	0.47
June	1.06	0.38
July	0.54	0.19
August	0.51	0.18
September	0.51	0.18
October	0.77	0.28
November	1.06	0.38
December	0.80	0.29

TABLE III (b)

Variations number of days

1912 (Calculated on 190,000,000 gallons per day)

LBS. POWDER PER DAY	NUMBER OF DAYS	PARTS PER M. POWDER	PARTS PER MILLION AVAIL. Cl. @35%
420	35	0.27	0.09
600	26	0.38	0.13
630	85	0.40	0.14
800	130	0.51	0.18
1,000	4	0.63	0.22
1,200	48	0.76	0.27
1,600	23	1.01	0.35
1,733	1	1.09	0.38
2,000	3	1.27	0.44
2,266	1	1.43	0.50
2,400	9	1.52	0.53

1913 (Calculated on 180,000,000 gallons per day)

LBS. PER DAY POWDER	LBS. PER DAY LIQUID CL.	NUMBER OF DAYS	PARTS PER M. POWDER	PARTS PER MILLION AVAIL. Cl. @36%
800		92	0.53	0.19
800	+ 90	14	0.53	0.25
800	+ 105	13	0.53	0.26
1,200		131	0.80	0.29
1,200	+ 10	1	0.80	0.30
1,200	+ 90	4	0.80	0.34
1,600		73	1.07	0.38
1,600	+ 90	4	1.07	0.41
2,000		15	1.33	0.48
2,400		14	1.60	0.58
3,360		3	2.25	0.81
3,480		1	2.32	0.84

HISTORICAL SKETCH OF USE OF LIQUID CHLORINE IN UNITED STATES FOR THE STERILIZATION OF WATER

The credit for the introduction of liquid chlorine for water disinfection belongs to Major C. R. Darnell, U. S. A.

He first tried it in June, 1910. In November, 1911, he published in the *Journal of the American Public Health Association* under the title of "The Purification of Water by Anhydrous Chlorine," a description of his apparatus together with the results of his experiments. He applied the chlorine in the form of a dry gas to the water to be treated.

Major Darnell carried out a series of tests with an apparatus with the capacity of 500 gallons per hour.

The Board of Officers of the War Department concluded (June, 1911,)

"That the apparatus is as efficient as purification by ozone or hypochlorite and is more reliable in operation than either.

"That it could be installed at a very low cost and that the cost of operation would be very slight."

In June, 1912, Dr. Geo. Ornstein constructed an experimental apparatus for the use of chlorine gas for water and sewage sterilization, employing an entirely different principle from Major Darnell, involving the absorption of the gas in water prior to its application to the fluid to be treated.

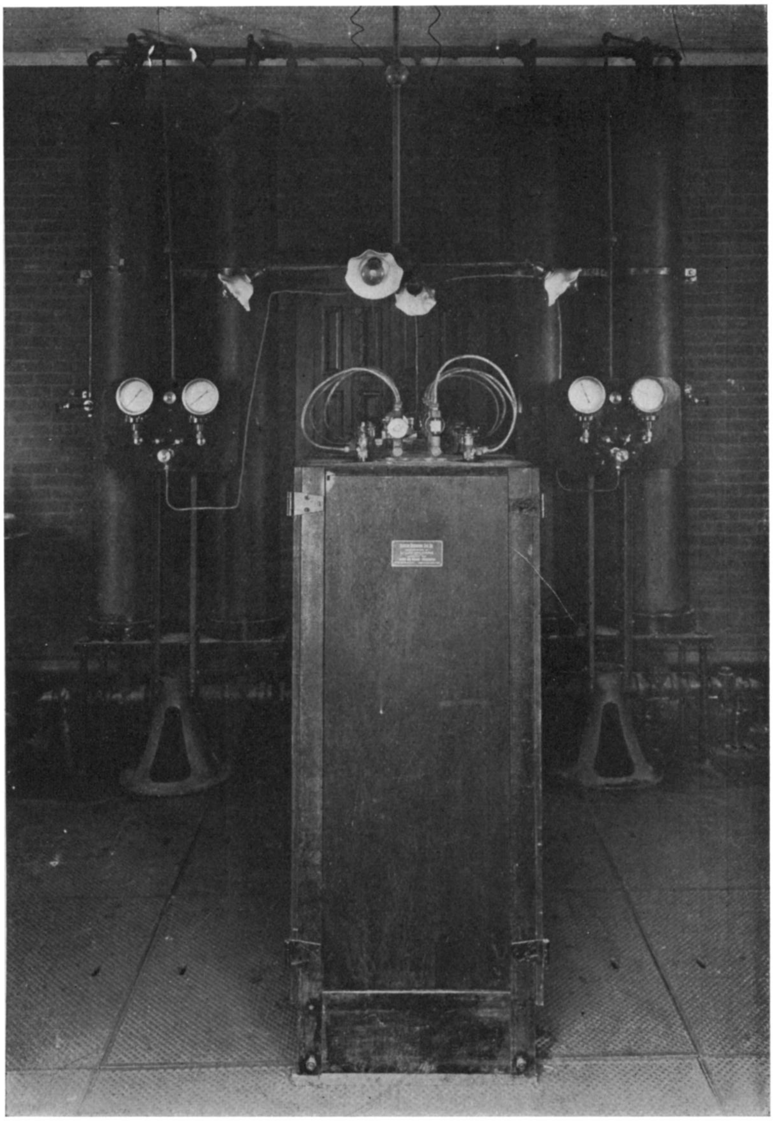
In September, 1912, Mr. Seth M. Van Loan, assistant chief engineer Philadelphia Bureau of Water, assisted by Dr. Geo. E. Thomas, chemist Belmont Laboratory, experimented with liquid chlorine on a large scale at Belmont Filter Plant. They fed the chlorine into the filtered water basin in the form of a gas, regulating the quantity by loss in weight of the containers, 46 pounds per day being applied to 38,000,000 gallons of water.

With the approach of cold weather the difficulty of freezing was encountered. Later the cylinder was jacketed and heated by a lamp.

Early in November Mr. John A. Kienle, chief engineer of the Water Department of Wilmington, Delaware, worked along similar lines at the Wilmington Plant. By the use of high and low pressure valves he was able to regulate the flow of gas. His results were presented at the 1913 Convention of the American Water Works Association. The apparatus used by him makes use of an absorption tower, whereby the chlorine is absorbed by a small amount of flowing water which carries it into the supply to be treated.

About the same time Mr. D. D. Jackson was experimenting at Ridgewood Reservoir, Brooklyn, and shortly afterward put out the Leavitt-Jackson Liquid Chlorine Machine. This machine operates on the basis of a balanced beam, feeding the gas according to loss in weight. The gas is fed directly into the water to be treated similarly to the Darnell apparatus.

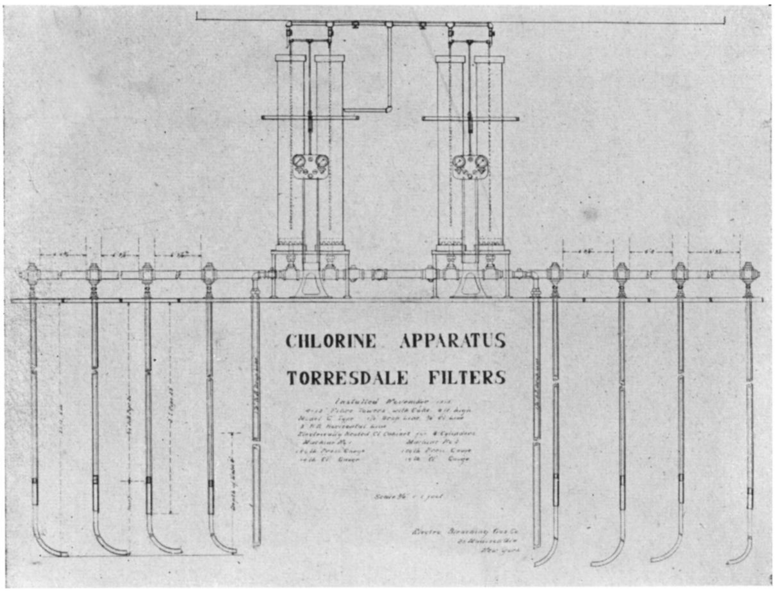
The first complete set of results for a continued period are those from the Niagara Falls Plant operated by the Western New York



No. 5. Liquid Chlorine Apparatus at Torresdale Filter Plant

Water Company under direction of Mr. H. F. Huy. (For the use of these results the author's thanks are due Mr. Huy and Mr. J. W. Ledoux.)

The first permanent Liquid Chlorine Plant in Philadelphia was installed at Queen Lane Filter Plant, September 1913. A contract for ten plants, two at each of the five filter plants, was awarded at a cost of $9750. The plants were installed during October and November, 1913; that at Torresdale starting November 25.



No. 6. Liquid Chlorine Apparatus at Torresdale—Showing Chlorine Feed Pipes

Cut No. 5 shows the present installation at Torresdale.

An elevation of the plant is shown on sketch No. 6.

LOCATION

The liquid chlorine plant is located at the inlet house of the filtered water basin (see plan of Torresdale Filter Plant).

This gate house is directly over two inlet chambers fed by a 10-foot conduit; the water enters the basin through eight 48-inch valves, four in each chamber.

GENERAL DESCRIPTION OF APPARATUS

From four to eight cylinders of liquid chlorine are connected by means of flexible copper coils to a manifold with a valve for each cylinder. The manifold is connected with a gauge used to determine initial pressure.

Beyond this gauge are two regulating valves; the first reducing the initial pressure to about 15 pounds per square inch and the second for regulating the pressure through a range sufficient to give the desired amount of gas. A low pressure gauge calibrated empirically indicates the flow of gas.

The gas then passes through a $\frac{3}{8}$-inch hard rubber pipe to the bottom of the first absorption tower. This tower is 8 feet high and is filled with coke to give surface. This tower is sealed; the excess gas passes through a second pipe to the bottom of a second tower.

These towers as well as all other parts from this point on are made of hard rubber. Water is admitted through the top of the towers.

The chlorinated water passes through a horizontal pipe 58 feet long, 4 inches in diameter connected with eight drops $\frac{3}{4}$ inch in diameter, extending to within one foot of the bottom of the chamber and protected from the current by $1\frac{1}{2}$-inch iron castings.

About three feet of flexible rubber hose is attached to the ends of these pipes. The ends of the hose are kept in motion by the swirl of the current.

ORIGINAL APPARATUS AND CHANGES THERETO

Owing to the large quantity of chlorine needed (as high as 10 pounds per hour) it was planned to feed the chlorine in liquid form through the cylinder valves having an evaporator placed next to the high pressure valve. This was done to prevent freezing owing to the reduction in temperature due to the rapid evaporation.

Cradles were provided for inverting the cylinders. The evaporator was prevented from freezing by having a constant flow of water passing around it.

From almost the start trouble was experienced. The needle and regulating valves of the apparatus gradually choked up with the impurities in the chlorine cylinders, chiefly ferric chloride. Liquid chlorine was allowed to pass through the feed pipe of the tower corroding and choking this up. Liquid chlorine found its way through the coil in the evaporator, where it came in contact with the water used for cooling, and the whole apparatus went out of commission. (In spite of all these difficulties a supply of chlorine was kept up with but two shut downs of any consequence.)

When it was found impossible to supply the gas in this manner the cylinders were used vertically and an electrically heated cabinet with automatic thermostatic control, as shown in cut, was installed. This keeps the cylinders at a temperature of 70°F. and but little trouble with freezing is experienced.

RESULTS FROM TREATMENT AT TORRESDALE, BELMONT, UPPER AND LOWER ROXBORO, QUEEN LANE, WILMINGTON, DEL., NIAGARA FALLS, AND ELSEWHERE

Liquid Chlorine Compared with Bleach at Torresdale Filter Plant

Liquid Chlorine has only been used by itself since February 8 so that it is difficult to get figures that are exactly comparable:

It was on the following data that the estimate of a strength of 1–6 was based.

Test No. 1. Comparing February 22 to March 31, 1912, with the same period of 1914 and with the period January 19 to February 28, 1914, when the condition of the water approached that of the early spring of 1912.

DATES	BACTERIA PER CC.			PER CENT REMOVED	B. COLI COMMUNIS			TREATMENT
	Applied	Effluent filters	Treated water		Tests	1 cc. +	10 cc. +	
A 1912 February 22 to March 31.	17,000	760*	260	64	39	2	13	9 pounds bleach per 1,000,000 gallons water
B 1914 February 22 to March 31..	6,800	320	30	90	39	0	5	1.3 pounds liquid Cl per 1,000,000 gallons
C 1914 January 19 to February 28	12,000	710	118	83	41	0	5	4.5 pounds bleach January 19 to February 9 inc. 8 pounds liquid Cl. per 1,000,000 gals.

* Approximate. + = B. Coli present.

The water during the period of February 22 to March 31, 1912, was the worst water that the Torresdale plant has been called upon to handle.

Comparing A with B the efficiency of 1.3 pounds per million gallons compared with 9 pounds bleach, a ratio of 1–7, was 90 per cent against 64 per cent.

Comparing C with A this is a substitution of .8 pounds of liquid chlorine for 4.5 pounds of bleach or a ratio of 1–6, the number of bacteria in the effluent was 118 against 250 and the per cent of B. coli was correspondingly lower.

Test No. 2. In January, 1914, 870 pounds bleach and 105 pounds liquid chlorine was used per day. In March 234 pounds liquid chlorine was used; this is a substitution of 129 pounds chlorine for 870 pounds bleach, a ratio of 1–6.7. The following results were obtained.

	BACTERIA PER CC.			PER CENT REMOVED	B. COLI COMMUNIS		
	Applied	Effluent filters	Treated water		Tests	1 cc. +	10 cc. +
1913							
January	13,500	900	227	75	31	2	5
March..	7,200	305	27	91	31	0	3

Test No. 3. Comparing November, 1913, with an average of 1620 pounds bleach per day and 90 pounds liquid chlorine during the last four days with March 1.3 pounds per million gallons or 234 pounds per day.

	BACTERIA PER CC.			PER CENT REMOVED	B. COLI COMMUNIS		
	Applied	Effluent filters	Treated water		Tests	1 cc. +	10 cc. +
November	8,500	170*	31	82	30	1	8
	7,200	305	27	91	31	0	3

* Approximate.

Test No. 4. Comparing April, 1913, with April, 1914.

	BACTERIA PER CC.			PER CENT REMOVED	B. COLI COMMUNIS			TREATMENT
	Applied	Effluent filters	Treated water		Tests	1 cc. +	10 cc. +	
1913 April....................	3,320	50*	10	80	30	0	0	7 pounds bleach per 1,000,000 gallons water
1914 April....................	2,070	89	11	88	30	0	1	1 pound liquid Cl

* Approximate.

Test No. 5. In February 800 pounds of bleach were used for eight days and during the month an average of one pound liquid chlorine per million gallons of water was used. The following results were obtained.

	BACTERIA PER CC.			PER CENT REMOVED	B. COLI
	Applied	Effluent filters	Treated water		
1914, February.....	7,250	460	99	78	4% positive in 10 cc.

In March with an effluent of 305 the treated water had a count of 27 per cc.

The complete data for the month of March, 1914, follow: 234 pounds liquid chlorine used per day or 1.3 pounds per million gallons water or .15 part chlorine.

TABLE IV

Daily tests at Torresdale for month of March, 1914

DATE MARCH 1914	BACTERIA PER CC.		EFFLUENT FILTERS			TREATED WATER, FILTERED WATER BASIN		
	River	Applied	Bact.	B. Coli		Bact. per cc.	B. Coli	
				1 cc.	10 cc.		1 cc.	10 cc.
1	13,000	3.400	200	0	+	5	0	0
2	1,600	850	140	0	+	12		
3	2,800	1,800	240	0	+	22		
4	4,000	1,800	240	0	+	14		
5	9,200	2,300	420	+	+	5		
6	9,200	3,200	140	+	+	25		
7	10,000	3,000	210	0	+	39		
8	2,700	1,900	50	0	0	9		
9	5,100	1,200	220	0	+	47		
10	10,000	220	160	0	+	4		
11	11,000							
12	10,000	3,900	200	0	+	9		
13	9,800	3,800	280	0	+	13		
14	12,000	3,600	260	0	+	30		
15	16,000	6,000	140	+	+	42		
16	24,000	4,500	270	0	+	59		
17	84,000	7,200	240	0	+	17	All 0 except 3d, 13th, and 20th on 10 cc.	
18	69,000	15,000	370	0	+	53		
19	91,000	7,400	500	0	+	35		
20	56,000	18,000	1,200	0	+	29		
21	44,000	32,000	920	+	+	230		
22	28,000	20,000	740	0	+	19		

TABLE IV—Continued

DATE MARCH 1914	BACTERIA PER CC.		EFFLUEMT FILTERS			TREATED WATER, FILTERED WATER BASIN		
	River	Applied	Bact.	B. Coli		Bact. per cc.	B. Coli	
				1 cc.	10 cc.		1 cc.	10 cc.
23	17,000	15,000	180	0	+	17		
24	12,000	6,200	240	0	+	14		
25	14,000	7,000	240	0	+	7		
26	12,000	6,600	140	0	+	10		
27	14,000	5,800	140	+	+	8		
28	14,000	5,500	100	0	0	10		
29	16,000	4,000	160	+	+	9		
30	40,000	5,200	170	0	+	14		
31	140,000	14,000	330	+	+	18		
		10,000	660	0	+	16		
Average.....	21,900	7,200	305			27		
Per cent of time positive				23	94		0	10

EFFICIENCY OF LIQUID CHLORINE AT SCHUYLKILL RIVER PLANTS, CITY OF PHILADELPHIA

The following tables show the result of treatment with liquid chlorine and chloride of lime at Belmont, Queen Lane, Upper and Lower Roxboro Filter Plants.

Amount of Organic Matter in Solution

The amount of oxidizable organic material in solution in the filtered water from the Schuylkill River averages less than one-half that of the Delaware or approximately .75 part per million.

BELMONT FILTER PLANT[1]

The table (No. V) gives the results for the first three months of 1912, 1913 and 1914; also November and December, 1913.

The actual effect of treatment at this and the other three plants can only be estimated as the disinfecting apparati are so placed that no tests of filtered, untreated water can be obtained.

Bleach was first used at Belmont, March 19, 1912.

In September, 1912, the experimental liquid chlorine plant was started. The results for January, February and March, 1913, show the effect of this crude apparatus combined with bleach.

On November 18 the improved machine was started, 42 pounds of chlorine being substituted for 220 pounds of bleach or about 1–5.

The chlorine was later reduced to a range of 33–39 pounds or approximately 1–6.

No direct comparisons are available except during November, 1913.

1st–17th inclusive 220 pounds bleach were used. Average bacteria count was 8 per cc. B. coli out of 17 tests were present in 1 cc. twice and in 10 cc. were positive six times.

18–30 inclusive 42 pounds chlorine were used. Average bacteria count was 4 per cc. B. coli out of 13 tests but one positive test and that on 10 cc.

On February 27, the Liquid Chlorine Plant was down for two hours and the count went up to 260 per cc.

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[1] Bacteria tests made by Dr. Geo. E. Thomas. Chemist in charge, Belmont Laboratory.

For the five and one-half months when chlorine was used out of 164 tests for B. coli only one positive test was obtained in 1 cc. and but 5 positive in 10 cc. or .6 per cent and 3.0 per cent.

In March, 1914, with an applied water of 10,700 bacteria per cc. the effluent averaged but five.

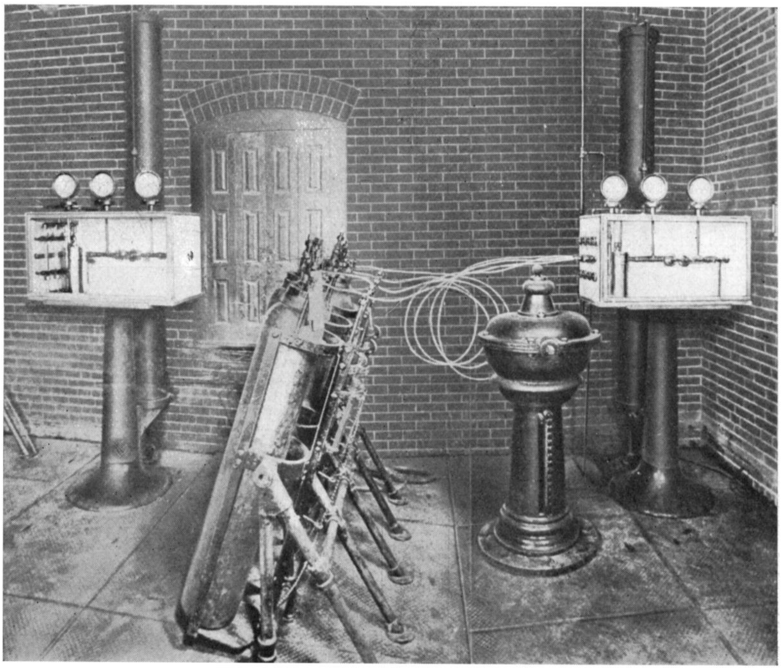
TABLE V

Showing the efficiency of Belmont Filter Plant

YEAR	BACTERIA PER CC.		B. COLI			TREATMENT
	Applied	Basin	Tests	1 cc. +	10 cc. +	
1912						
January	1,940	622	14	6	9	None.
February	36,000	456	11	0	6	None.
March	38,400	354	31	2	16	Bleach March 19, 168 pounds, 4 per 1,000,000 gallons water
1913						
January	19,200	25	31	0	8	155 pounds bleach 40 pounds Cl day.
February	28,900	12	28	0	1	Bleach for 10 days at 35 pounds, chlorine 28 days at 39 pounds.
March	69,000	11	31	1	1	Bleach 18 days at 128 pounds, chlorine 18 days at 37 pounds.
November	4,270	6	30	2	7	220 pounds bleach to 17th, 42 pounds chlorine 18–30 inclusive.
December	20,200	25	31	1	2	Chlorine 34.5 pounds per day.
1914						
January	20,800	63	31	0	2	Chlorine 33 pounds per day.
February	14,000	7*	28	0	0	Chlorine 39 pounds per day.
March	10,700	5	31	0	0	Chlorine 37 pounds per day.

* Omitting February 27 plant out two hours count 260 per cubic centimeter.

	LBS. PER 1,000,000 GALS.	PARTS PER MILLION
1913		
December	0.88	0.11
1914		
January	0.83	0.10
February	0.98	0.12
March	0.93	0.11



No. 7. Liquid Chlorine Apparatus Belmont Filter Plant—Showing Cradles Since Abandoned

TABLE VI

Showing efficiency of Queen Lane Filter Plant

YEAR	BACTERIA PER CC.		B. COLI			TREATMENT
	Applied	Basin	Tests	1 cc. +	10 cc. +	
1913						
January	4,250	35	26	4	16	None
February	4,230	22	14	0	7	None
March	1,540	114	18	2	13	None
October	4,370	8	62	3	31	10 lbs. chlorine North Basin 90 lbs. bleach South Basin
November	2,250	6	60	0	6	34.5 lbs. chlorine per day
December	2,480	8	62	0	4	34.5 lbs. chlorine per day
1914						
January	3,140	26	62	2	4	36 lbs. per day chlorine
February	1,920	6	56	0	1	47 lbs. chlorine per day
March	1,520	5	58	0	1	37½ lbs. chlorine per day

	LBS. PER 1,000,000 GALS.	PARTS PER MILLION
1913		
November	0.70	0.09
December	0.70	0.09
1914		
January	0.72	0.09
February	1.00	0.12
March	0.75	0.09

TABLE VII

Showing efficiency of Lower and Upper Roxboro Filter Plants

Lower Roxboro Filters. Output approximately 10,000,000 gallons per day.

YEAR	BACTERIA PER CC.		B. COLI			TREATMENT
	Applied	Basin	Tests	1 cc. +	10 cc. +	
1911						
January	35,800	428	13	2	5	None.
February	14,000	515	10	2	2	None.
March	42,500	128	13	1	4	None.
1912						
January	27,700	580	14	5	7	First bleach January 26, 40 pounds per day.
February	40,600	47	11	0	0	47 pounds bleach per day.
March	33,500	83	27	0	0	60 pounds bleach per day.
1913						
January	12,800	12	31	0	3	32 pounds bleach per day.
February	21,500	8	28	0	0	32 pounds bleach per day.
March	43,800	40	31	0	1	32 pounds bleach per day.
November	3,940	2	30	0	1	Liquid Cl 6 pounds 2 days. Bleach 48 pounds 2 days both 2 days
December	12,600	9	29	0	0	Cl 6 pounds, 11d 3.5 pounds 20 days.
1914						
January	11,050	61*	31	0	2	Cl 5 pounds per day.
February	7,630	16	28	0	0	Cl 9 pounds per day.
March	10,650	5	29	0	0	Cl 9.5 pounds per day.

* Omitting 27–29 aver. = 21.

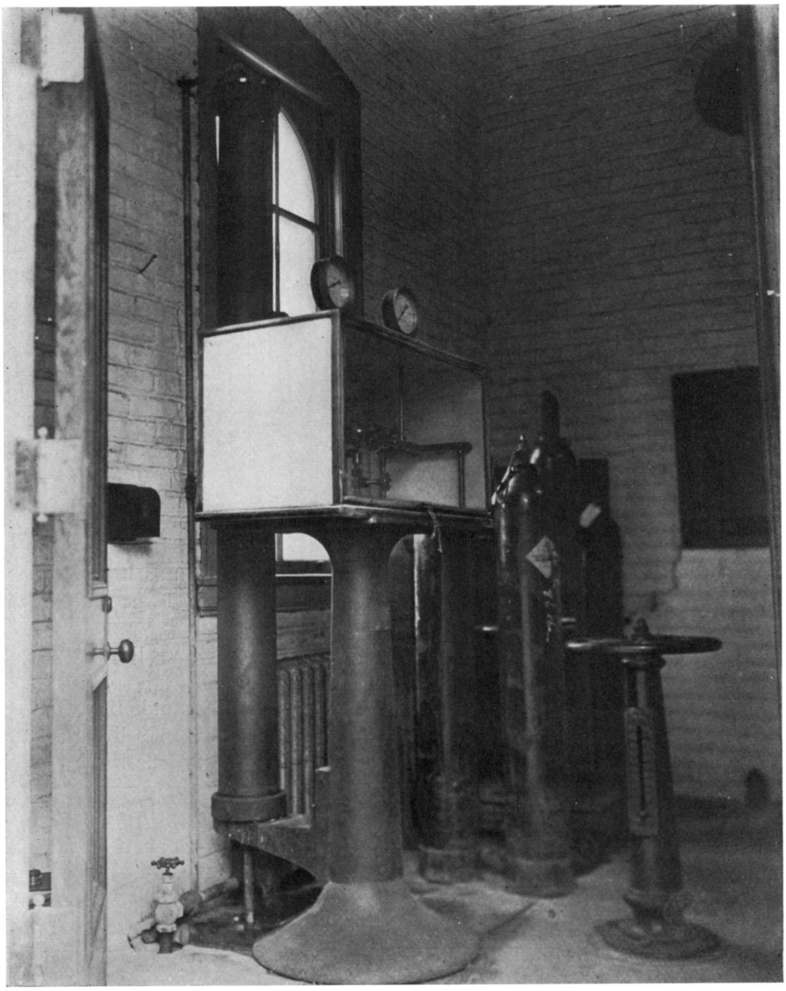
TABLE VII—Continued

Upper Roxboro Filters. Output approximately 15,000,000 gallons per day.

YEAR	BACTERIA PER CC.		B. COLI			TREATMENT
	Applied	Basin	Tests	1 cc. +	10 cc. +	
1911						
January	13,600	69	13	1	2	None.
February	13,500	24	10	0	0	None.
March	7,510	20	13	0	2	None.
1912						
January	7,150	92	14	1	6	First bleach January 27, 4 pounds per 1000.
February	12,200	19	11	0	1	80 pounds bleach per day.
March	20,000	38	27	0	3	94 pounds bleach per day.
1913						
January	2,450	6	31	0	0	45 pounds bleach per day.
February	3,240	8	28	0	0	45 pounds bleach per day.
March	2,700	8	31	0	2	45 pounds bleach per day.
November	960	1	30	0	0	1–8, 3 pounds Cl, 72 pounds bleach. 9–30, 9 pounds liquid Cl.
December	4,650	2	31	0	0	9 pounds liquid Cl.
1914						
January	2,460	4	31	0	1	9.5 pounds liquid Cl.
February	3,140	3	28	0	0	14 pounds liquid Cl.
March	2,600	2	30	0	0	14 pounds liquid Cl.

Liquid chlorine

	LOWER ROXBORO		UPPER ROXBORO	
	Lbs. per million gals.	Parts per million	Lbs. per million gals.	Parts per million
1913				
November	0.6	0.07	0.6	0.07
December	0.4	0.05	0.6	0.07
1914				
January	0.5	0.06	0.6	0.07
February	0.9	0.11	0.9	0.11
March	0.9	0.11	0.9	0.11



No. 8. Liquid Chlorine Apparatus Queen Lane Filter Plant

QUEEN LANE[2]

This plant was started January, 1913.

Table VI shows a comparison between untreated water and water treated with liquid chlorine. The need for treatment is shown by the results for March, 1913, with an applied of 1540 the effluent was 114. (This is from a green plant.)

In October 10 pounds chlorine were applied to the north basin and 90 pounds bleach to the south basin. Although the average bacteria count was but 8, B. coli was present in 10 cc.

B. Coli

North Basin	10 pounds chlorine	31 tests	1 cc.+2	10 cc.+15
South Basin	90 pounds bleach	31 tests	1 cc.+1	10 cc.+16

From November, 1913, to April, 1914, inclusive with about ¾ pound chlorine per million gallons, the average number of bacteria in the basin was 10 per cc., and B. coli out of 358 tests for 1 cc., 2 or .56 per cent were positive, and for 10 cc. 16 or 4.5 per cent.

LOWER ROXBORO[2]

Table VII shows the relation between untreated, treated with bleach and treated with liquid chlorine.

In November, 1913, a substitution of 6 pounds of liquid chlorine per day was made for 48 pounds of bleach. This 6 pounds was reduced to 3.5 pounds or .35 pound per million gallons on December 12, the count for December averaging but 9 with B. coli absent. Excellent results were obtained with but 3.2 pounds of bleach per million gallons of water.

Since the introduction of liquid chlorine, to April 30, at Lower Roxboro, out of 168 tests for B. coli not ONE positive test in 1 cc. was obtained, and only three in 10 or 1.8 per cent.

UPPER ROXBORO[2]

This is the banner plant of the city. Its high efficiency in the past without treatment has largely been due to the fact that eight days sedimentation precedes filtration. The table shows the results from untreated, treated with bleach, and treated with liquid chlorine. The counts are so uniformly low both with the use of bleach and with liquid chlorine that it is hardly possible to compare counts of 2

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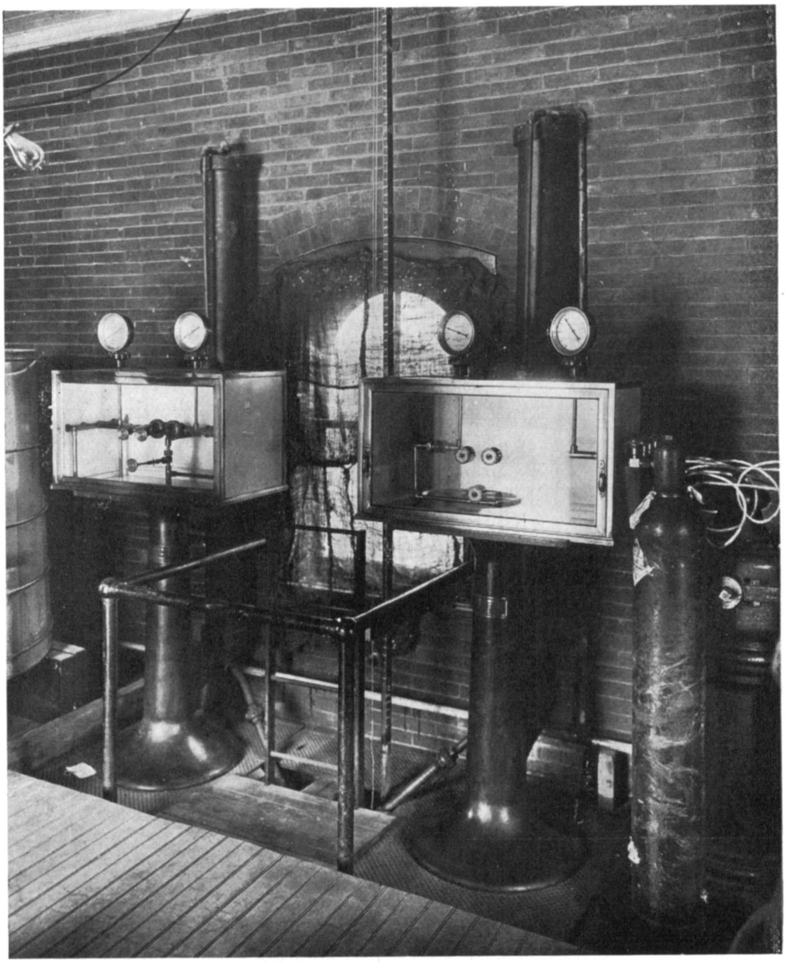
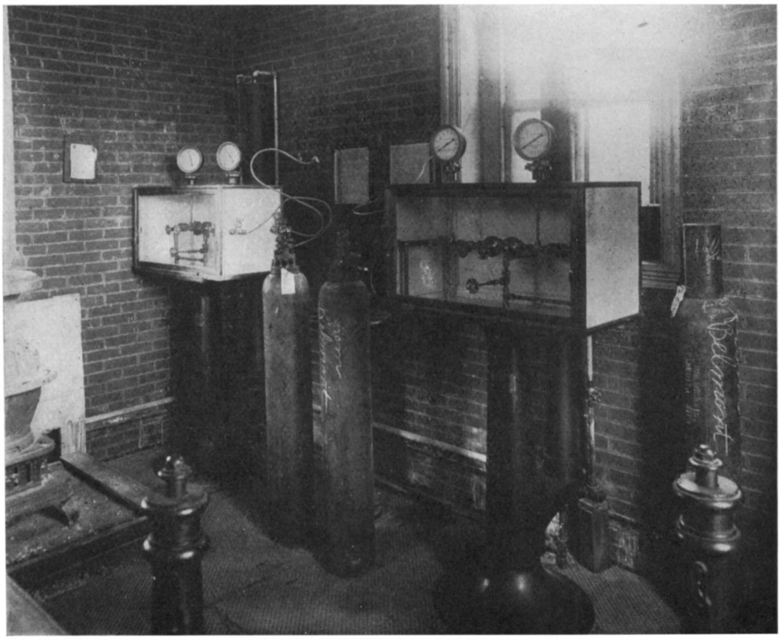
[2] Bacteria tests made by Dr. Geo. E. Thomas, Chemist in charge, Belmont Laboratory.



No. 9. Liquid Chlorine Apparatus Upper Roxboro Filter Plant

with 8 or 1 with 6. It is sufficient to note that since the introduction of liquid chlorine in November, 1913, an average count of but three has been obtained and that there has been but one positive test for B. coli out of 172 tests and that in 10 cc.

The amount of 14 pounds chlorine per day seems excessive, in fact on April 14 the amount of chlorine used at all the Schuylkill plants with the exception of Queen Lane was reduced to ½ per million gallons or a cost of but 5 cents per million.



No. 10. Liquid Chlorine Apparatus Lower Roxboro Filter Plant

Summary of Schuylkill plants, November 1913–March 1914 inclusive

PLANT	B. COLI COMMUNIS				
	Tests	1 cc.	Per cent	10 cc.	Per cent
Queen Lane	358	2	0.56	16	4.5
Belmont	164	1	0.61	5	3.0
Lower Roxboro	168	0	0	3	1.8
Upper	172	0	0	1	0.58
Totals	862	3	0.35	25	2.9

WILMINGTON, NORTH CAROLINA

The writer is indebted to Mr. Geo. F. Catlett, Chemist, Consolidated Boards of Health, Wilmington, North Carolina, for a very complete account of the water conditions at Wilmington, including experiences with bleach and liquid chlorine, a part of which is presented here.

Source of supply, Cape Fear River, capacity 4,000,000 gallons daily. Output about 2,000,000 gallons.

Analysis of water

	RIVER	FILTERED
Color	100–200	0–20
Alkalinity	5–7	9–14
Turbidity	10–50	0–5
Oxygen consumed	16.9	3.9 (30 min. Boil?)
Bacteria per cubic centimeter	2000–3000	50–200
B. coli	Present 1 cc.	Present 10 cc.

Type of Plant: Mechanical, 8 filters, 500,000 gallons capacity.

Treatment 3 to 3.5 grains per gallon alum together with the necessary soda ash used to coagulate the water and remove color.

Filtered water treated with bleach and later liquid chlorine.

Bleach added to filtered pump well corroded plungers and packings. Later a small force pump was used on the discharge side of the pumps. This became clogged with lime sludge. Quantity of bleach 3 parts per million available chlorine.

By May, 1913, the sand on the filters was allowed to get so low that the filters showed B. coli in 1 cc. The Board of Health insisted on the restoring of sand and the application of a proper bleach apparatus. The use of a liquid chlorine machine was recommended and a machine installed.

Table VIII gives the averages for ten months of raw, filtered and treated (with bleach). Three-tenths part of available chlorine, about 8 pounds powder per million was used. It will be seen that the treated water had a comparatively high count and that the bleach removed about 67 per cent of the bacteria. The substitution of .18 part of liquid chlorine while it removed 80 per cent of the bacteria did not remove all B. coli and 158 bacteria per cc. remained. During this period the filters were being resanded.

TABLE VIII

RESULTS OF TREATMENT AT WILMINGTON, NORTH CAROLINA

Monthly averages (showing gradual deterioration of filter efficiency)

BACTERIA PER CC.			B. COLI COMMUNIS PER CENT POSITIVE						COLOR TURBIDITY			
Raw	Filtered	Treated	Raw		Filtered		Treated		Raw	Filtered	Raw	Filtered
			10 cc.	1 cc.	1 cc.	10 cc.	1 cc.	10 cc.				
1,860	63	21	0	50	0	0	0	0	114	9	27	0.25
2,190	57	36	100	100	0	0	0	0	115	10	32	1.5
2,775	86	24	80	100	0	0	0	0	137	8	25	0.75
1,800	78	19	20	87	0	12	0	0	122	7	35	1.0
2,700	196	61	0	100	8	25	0	3	126	9	21	slight
2,900	258	87	0	33	26	40	0	12	150	12	22	0.75
1,750	286	126	0	50	30	100	0	18	136	14	39	3.5
2,825	348	113	0	100	40	100	0	0	175	16	21	0.5
2,240	640	99	0	75	56	100	26	60	116	18	43	9.0
1,280	782	158	0	60	60	100	21	37	146	16	31	slight
Av. 2,230	279	74							134	12	30	
Per cent removed.	87.5	73.5*										

0.1 cc. tests of filtered and treated water all negative.

* 10 cc. tests all positive.

3 ppm. Hypo used except last month when 0.18 ppm. liq. chlorine used.

Table IX gives the daily results November 17 to December 22, 1913, with the use of .3 part liquid chlorine.

Mr. Catlett, writing April 6, states: "After the filters were repaired we went back to .18 parts chlorine (1.5 pounds per million gallons) and our water as it goes to the consumer is almost sterile,

TABLE IX

Wilmington, North Carolina. Daily averages after application of 0.3 p.p.m. liquid chlorine (raw water averaging about the same as in table I)

DATE	BACTERIA PER CC.		B. COLI COMMUNIS				COLOR, FILTERED	TURBIDITY
	Filtered	Treated	Filtered		Treated			
			1 cc.	10 cc.	1 cc.	10 cc.		
November								
17	125	16	+	+			5	
18	320	6	0	+			5	
19	215	3	+	+			10	
20	180	5	0	+			10	
21	135	8	0	+			5	
22	98	6	0	+			5–10	
24	105	2	0	+	All negative		0–10	
25	200	12	+	+			5	
26	135	2	0	+			10	
28	255	6	+	+			10	
29	340	4	+	+			5	all 0
December								
3	135	3	0	+			10–15	
4	160	4	0	+			15	
5	140	5	+	+			5–10	
6	210	4	0	+			10	
8	95	3	0	+			5–15	
9	325	6	+	+			5	
10	80	5	0	+			5–10	
11	75	15	0	0			5–10	
12	95	11	0	0			10	
13	120	23	0	+			25	
15	185	16	0	+			10–30	
16	140	10	0	+			10–20	
17	65	12	0	0			5–15	
19	50	4	0	+			5	
20	65	2	0	0			5–10	
22	75	2	0	0			5–10	
Average	153	8						
Per cent removed		94.8	Note filters were being repaired during this period					

and continues so from day to day without interruption. The chlorination apparatus gives no trouble; with the exception of some minor leaks, it is only necessary to couple up a new tank of chlorine when empty. We can now use the man's time formerly spent in mixing and preparing the bleach for other purposes. The new installation requires about one-tenth the attention." The reason attributed by Mr. Catlett for the need of more chlorine than we find necessary is the fact "That the raw water contains an abnormal amount of organic matter, brought down from the swamps in the water shed and a good part of the oxygen is used by this."

WILMINGTON, DELAWARE. RESULTS OF HYPO AND CHLORINE TREATMENT

The following figures are taken from the annual report of Mr. Edgar M. Hoopes, Chief Engineer, Water Department, Wilmington, Delaware.

Year 1912 February to April 27, inclusive.

Quantity of bleach, 7 to 22½ pounds per million gallons, average 11½ pounds.

	Bacteria per cc.	
Applied	39,600	
Effluent filters	2,400	This is a removal of 94 per cent
Treated	150	

Year 1913 March to June inclusive.

Liquid chlorine average 1.56 pounds per million gallons, ratio 1 to 7.

	Bacteria per cc.	
Applied	9,100	
Effluent filters	102	A removal of 85 per cent
Treated water	15	

In March *Journal of the American Water Works Association* Mr. Hoopes writes that during eight months in 1913 when he used an average of 1.56 pounds chlorine the bacteria count was:

Before treatment	302	
After treatment	51	83 per cent removed
B. coli	11.97	
After treatment	2.77	77 per cent removed

The condition of the water treated with chloride of lime and that treated with liquid chlorine are not exactly comparable, one having about 2400 bacteria per cc. and the other an average of 302.

USE OF LIQUID CHLORINE WITH UNFILTERED WATERS

MONTREAL, CANADA

Mr. John H. Harrington, chemist in charge, supplies the following information.

"Liquid chlorine has been used at the Low Level Pumping Station since December, 1913, and has given satisfactory results on raw waters of widely varying alkalinity and organic content. The water at the intake is made up of varying proportions of water from the St. Lawrence and Ottawa rivers the general characteristics of which are as follows:

Results of liquid chlorine treatment at Montreal, Canada. Parts per Million

	ALKALINITY	OXYGEN ABSORBED (30 MIN.)	DOSE REQUIRED CHLORINE	BACTERIA PER CC.	PER CENT REMOVED
Ottawa	20	14.0	1.50	3000	over 98
St. Lawrence	90	3.5	0.30	300	over 99

"For mixtures of the two the dose is larger as the proportion of Ottawa water is larger." This is a dose of from 2.5 to 12.5 pounds of chlorine per million gallons. Mr. Harrington makes no mention of taste. It is presumed the water does not have a taste.

NIAGARA FALLS, NEW YORK. PLANT OF WESTERN NEW YORK WATER COMPANY

Liquid chlorine was used throughout the year 1913, 1½ pounds per million gallons of water being used with 1.17 grains per gallon alum, with the raw water and ½ pound liquid chlorine per million gallons used with filtered water.

In 1912 July to December, inclusive, an average of 1.85 grains per gallon of alum were used with 3.92 pounds hypo per million gallons water (hypo applied to filtered water). In 1913 1.17 grains alum were used, or a saving of nearly .7 grain per gallon or at 1 cent per pound about 90 cents per million gallons water by using 1 pound liquid chlorine per million gallons.

In 1912 thirty pounds of chloride of lime were used for 6,000,000 gallons of water, applied to the effluents of the filters.

Water is pumped to settling basin, treated with alum and liquid chlorine, flows by gravity to filters and clear well, final effluent treated with liquid chlorine. By the use of 1½ pounds chlorine Mr. Huy, the engineer in charge, states that he was able to make a material saving in the amount of alum needed.

The following table (X) summarizes the results with liquid chlorine for the year 1913.

1914, January to March, inclusive.

Raw water averaged 23,600 bacteria per cc.

Treated water averaged 17 bacteria per cc. with but 1 positive test for B. coli out of 227—1-cc. tests.

In 1912 during the same time the treated water averaged 44 bacteria and B. coli was present in 1 cc. 4.8 per cent of the time.

The above table shows the increased efficiency of liquid chlorine when used with filtered waters compared with its use with unfiltered water (see also results from Montreal).

ADVANTAGES OF LIQUID CHLORINE OVER CHLORIDE OF LIME

There are several claims made for liquid chlorine, an analysis of which may prove of value.

1. That liquid chlorine is an absolutely pure chemical, concentrated in small cylinders while chloride of lime is bulky, requiring large space for storing.

As far as we have been able to determine the liquid chlorine we have handled is pure, the chief impurity being ferric chloride, due to the action of the chlorine on the cylinder.

2. As to the saving in space required a 100 pound cylinder occupies 64 square inches floor space. A stock for 50 days at 200 pounds a day would occupy a space of 45 square feet 5 feet high.

Twenty thousand pounds of bleach enough for but 17 days at 1200 per day would occupy (taking the cans at 750 pounds each) 160 square feet. On a basis of 6 to 1 about 10 to 11 times as much space is required for bleach as for liquid chlorine.

3. With efficient controlling devices liquid chlorine will eliminate the disagreeable odors and corrosive influences of chloride of lime; consequently the installation may be placed in positions where the use of chloride of lime is impossible.

TABLE X

Plant W. N. Y. W. Co., Niagara Falls, Monthly averages

1913 MONTH	BACTERIA PER CC.			B. COLI PER CENT +			TURBIDITY		GRS. ALUM PER GAL.	LBS. Cl M.
	Raw	Settled	Filtered	Treated	Filtered	Treated	Raw	Filtered		
January	18,300	3,450	334	40	49	4	404	0	1.98	1.59
February	19,700	4,890	363	42	51	2	139	0	1.23	1.65
March	30,800	4,580	352	51	46	6	394	3	1.94	1.79
April	24,900	3,310	253	21	18	0	158	0	1.29	2.14
May	33,800	7,320	422	22	30	0	80	0	1.20	2.17
June	39,000	10,100	894	27	64	0	42	0	0.91	1.86
July	43,500	7,570	564	24	68	2	48	0	0.88	1.99
August	32,000	4,370	414	22	71	0	20	0	0.81	2.11
September	33,000	3,640	322	17	47	0	16	0	0.80	2.23
October	30,700	4,010	334	13	28	0	39	0	0.88	2.07
November	27,500	3,910	280	14	24	0	86	0	1.12	2.39
December	19,700	3,070	352	11	36	1	95	0	1.05	2.12
Average	29,400	5,020	407	25	43	1.3	126.6	0	1.17	2.01
Per cent removed		82.9	91.9	93.9						
Per cent removed plant				99.92						
Per cent removed B. coli					56.6	97.2				

Ordinarily this is true. The odor of chlorine at Torresdale is hardly noticeable; but there are times when, due to carelessness or accidents, the atmosphere has been unbearable and chlorine has escaped in large amounts. (This has usually been caused by the failure of the water supply used for absorption and not by the apparatus.)

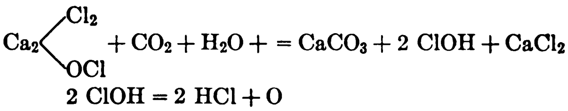
4. Liquid chlorine will retain its full efficiency over unlimited time whereas chloride of lime deteriorates rapidly. This is one of the best arguments for liquid chlorine, especially for small installations.

5. The floor space occupied by liquid chlorine plants is small, whereas chloride of lime installations require large mixing tanks, etc.

The space occupied at Torresdale for bleach treatment independent of the space for weighing was 22 feet by 16 feet; for the liquid chlorine apparatus; the cabinet is 2 feet by 4.4 feet and the space occupied by the towers is 10 feet by about 2 feet.

6. The reaction with liquid chlorine is simplified, while that with chloride of lime is complex and less effective at low temperature.

The reactions for chloride of lime probably are



$$Ca_2\left\langle\begin{matrix}Cl_2\\ OCl\end{matrix}\right. + CO_2 + H_2O + = CaCO_3 + 2\ ClOH + CaCl_2$$

$$2\ ClOH = 2\ HCl + O$$

$$2\ HCl + CaCO_3 = CaCl_2 + H_2O + CO_2$$

Jackson (Sterilization of Cleveland Water Supply) gives the first part of the reaction as $CaOCl_2+H_2O+CO_2=CaCO_3+HOCl+HCl$.

LIQUID CHLORINE

Jackson gives $Cl_2+H_2O=HOCl+HCl$ and $HOCl+HCl=HCl+O$.

It is a question if hypochlorous acid is formed and the author prefers the simple reaction of $Cl_2+H_2O=2\ HCl+O$.

This is a liberation of 23 per cent by weight of nacent oxygen and which together with the powerful disinfecting action of the chlorine itself acting before it decomposes water gives the increased efficiency.

It has been noticed in some places (Belmont Filter Plant in 1912) where the dry gas has been fed directly into the water to be treated, that bubbles rise to the surface, especially when large amounts are used. This is due to the fact that the specific gravity of the gas is so low that it rises to the surface before it has time to be absorbed by the water. At 234 pounds a day we use 2.6 ounces per minute or at 0°C 760 mm. pressure about 1420 cubic inches per minute or nearly one cubic foot.

7. According to Mr. D. D. Jackson (Proceedings American Water Works Association, 1913) 1 pound liquid chlorine equals 9 pounds chloride of lime; according to Mr. J. A. Kienle (Proceedings American Water Works Association, 1913) it equals eight. Theoretically it should equal about three, but in practice considerable available chlorine is lost and the theoretical amount is nearer 1 to 4.

Mr. Huy at Niagara Falls claims to get as good results with 3 pounds of liquid chlorine per day with 6,000,000 gallons of water as he did with 30 pounds of powder. He added 30 pounds to the filter effluent. He added 9 pounds liquid to the water in the sedimentation basin and 3 pounds to the effluent of the filters. The results are not quite comparable.

At Torresdale we are using liquid chlorine at the rate of about 1 to 6 to 1 to 7. It is quite possible that with careless handling and storing of bleach at small plants the figure is nearer 1 to 8 than 1 to 6.

8. No taste or odor appears in water treated with liquid chlorine.

Major Darnell states that at least two parts of liquid chlorine equivalent to 16 pounds per million gallons must be used to give the slightest taste to Potomac River water. Mr. Huy stated that when using 5 pounds per million gallons a slight taste was noticed in the laboratory directly after dosing. On a test at the Connecticut Hospital for the Insane, Middletown, Connecticut, 14 pounds per million gallons were used without its being noticed.

It is quite possible that if the dosage is heavy enough the water will have a taste. Figuring on a basis of 6–1, 30 pounds of chloride of lime would be needed to correspond to Mr. Huy's 5 pounds; and 80 pounds to the amount mentioned by Mr. Darnell.

From a close examination of the literature on chloride of lime and from personal observation, the amount of chloride of lime that will give a taste to water may be estimated at from 7 to 20 pounds per million gallons water, the average figure will be from 10 to 12. At the above rating this would mean 2 pounds liquid chlorine. A heavy overdose can be given without complaints.

9. Liquid chlorine does not change the character of the water by the introduction of lime salts. The lime salts will usually amount to not over one part per million.

10. Liquid chlorine necessitates no labor cost while chloride of lime does. This is true, but a liquid chlorine requires skilled supervision to be operated properly and is not fool proof.

11. Liquid chlorine leaves no sludge. This is self-evident.

12. Liquid chlorine will reduce the amount of alum needed for bacterial removal. There can be no question but that, in cases where the water is comparatively clear and where alum is used chiefly for bacteria removal, if liquid chlorine is used before filtration it will make a marked saving in the cost of alum and in many cases will not only pay for itself but will decrease the general cost of the plant.

A saving of one-half grain per gallon of alum at 1 cent per pound by the use of 1 pound liquid chlorine per million gallons at 10 cents means a saving of 61 cents per million gallons.

13. The feed of liquid chlorine is regular from hour to hour and the feed of chloride of lime varies constantly.

The irregularity of the feed of bleach at Torresdale under the best of conditions was shown in the first part of this paper.

We make readings of the gauges on the liquid chlorine machines every hour and a half and the fluctuations during any one day will not ordinarily vary over one-half pound from the desired amount.

That the disinfection is continuous throughout the twenty-four hours is shown by the following table (XI) giving maximum, minimum and average results of tests every two hours for fifteen days.

Samples marked House No. 2 Lardner's Point were collected from Pump No. 10, Lardner's Point Pumping Station, three miles from Torresdale Basin. The averages are averages of 12 tests made every two hours. The samples from the effluent of the filters and the filtered water basin are collected at 9 a.m.

OBJECTIONS OF USE OF LIQUID CHLORINE

The chief objection to the use of liquid chlorine lies in the concentrated energy of the material itself. If liquid chlorine is set free in small enclosures it will cause nausea. With ordinary common sense and judgment on the part of the operator this is not likely to happen. The greatest danger lies in faulty cylinders and faulty valves. If the cylinder valve will not turn off, or if the cylinder leaks, it must be gotten out to the open air and the chlorine allowed to escape. Careful inspections of cylinders and valves must be made. Liquid chlorine when it comes in contact with moisture has a very corrosive action, but this has been overcome by the use of hard rubber pipes and towers.

The above summarizes the advantages of liquid chlorine; the objections are comparatively few in number.

TABLE XI

Showing regularity of disinfection. Bacteria per cubic centimeter

DATE	EFFLUENT FILTERS	FILTERED WATER BASIN	LARDNER'S POINT HOUSE NO. 2			
			Maximum	Minimum	Average	Liq.Cl. lbs. per M. gals.
March						
28	160	9	28	7	13	1.3
29	70	14	20	6	13	1.3
30	330	18	25	8	15	1.3
31	660	16	23	10	17	1.3
April						
1	520	11	28	8	16	1.3
2	680	51	41	4	16	1.3
3	200	15	24	6	15	1.3
4	170	10	27	8	14	1.3
5	120	16	51	7	17	1.3
6	71	8	29	3	12	1.3
7	62	8	16	5	9	1.2
8	47	8	15	6	9	1.0
9	57	9	15	6	10	1.0
10	45	18	14	9	12	1.0
11	94	18	17	9	13	1.0

COMPARATIVE COSTS

The following estimated comparative figures are submitted:

Chloride of lime costs us from $1.22 to $1.70 per 100 pounds, the usual quotation was $1.34 and the average figure $1.40.

Taking $1.40 as a basis; we used during 1913 an average of a little over 1200 pounds a day or $16.80 a day for powder.

Two laborers at 25 cents per hour were employed for eight hours or $4 per day, making a total cost of $20.80 per day exclusive of repairs, sample collecting or laboratory analyses.

One hundred and eighty pounds of liquid chlorine (the amount used April 10) would cost at 10 cents per pound $18 per day.

We have now passed the worst conditions of the year, February and March, when we used 234 pounds a day or $23.40 cost.

It is expected that we will be able to reduce the amount of liquid chlorine to at least three-fourths pound per million or 120 pounds a day. We reached this April 22.

Some supervision and handling of cylinders is required. At present the work is done by a $3 a day mechanic who also keeps the pre-filters in repair. His wages are charged against the pre-filters. A charge of $1 per day would be fair for this service. This is partly balanced by the discontinuance of laboratory analyses.

The labor cost during 1913 of $4 per day at Torresdale with its output of 180,000,000 gallons amounted to but 2.2 cents per million gallons. At Belmont and at Queen Lane the labor cost of about $1.50 per day amounted to 3.8 cents and 3 cents respectively.

At the Roxboro plants the labor cost averaged over $1 per day for mixing; this at Lower Roxboro cost 10 cents per million and at Upper Roxboro 6.7 cents per million.

The cost per million gallons at these plants during 1913 amounted to 16 to 18 cents. At 1 pound per million gallons for liquid chlorine the cost would be 10 cents, or a saving of 6 to 8 cents per million gallons. On April 14 the quantity used was reduced to one-half pound per million or a cost of 5 cents, a saving of 11 to 13 cents per million.

Belmont and Queen Lane are saving a labor cost of 3.8 and 3 cents per million gallons. Belmont is operating at a rate of one-half pound and Queen Lane at one-half pound or about 5 cents each.

On April 21 the amount used at Torresdale was reduced to three-fourths pound or a cost of $13.50 per day exclusive of a possible charge of $1 for labor.

In general the cost of the two processes should be about equal; if anything, liquid chlorine should prove the cheaper.

GENERAL SUMMARY AND CONCLUSIONS

Disinfection has been found absolutely necessary at Torresdale; at least one-half part of chloride of lime, or the minimum we reached in 1913 of 800 pounds a day, is needed.

With the use of liquid chlorine it is necessary to have an accurate determination of the flow of gas; it must be kept in a condition that it will not corrode the apparatus and a proper absorption of the gas must be obtained. This has been accomplished by the use of absorption towers, which require from 50 to 100 gallons of water per 1 pound of chlorine used.

While in some instances liquid chlorine may prove more costly than chloride of lime; the regularity with which it can be applied, the more effective action on pathogenic bacteria, the small compact apparatus and the absence of the odor of chlorine around the plant, recommend it as a satisfactory substitute for hypochlorite, having as it does all the advantages of the latter and only some of the faults.

DISCUSSION

Mr. Wilson F. Monfort: The speaker has been very much interested in Mr. West's paper, and regrets that at St. Louis we were unable to contribute anything, because the water we were treating with liquid chlorine so rarely showed any indications of the B. coli. We had negative results before treatment regularly, almost universally, and the disinfecting action was almost nil.

There is one question that has been brought up with regard to the relative efficiency of hypochlorite of lime and liquid chlorine that should be pushed a little further. It is not the matter of cost, it is the matter perhaps of uniformity of application as affecting after-growths that have been commonly noted for a number of years where hypochlorite of lime is used. The speaker desires to raise that question and hopes that Mr. West may be able to give us an answer, as to whether he has discovered any after-growths in the use of hypochlorite or when using liquid chlorine? It has occurred to the speaker that the liquid chlorine diffusing so very rapidly there is a possibility of much more efficient sterilization of the water; whereas the hypochlorite solution, as often made, is diluted and may be diffused much less rapidly, and the efficiency of application be considerably lower. If it be true that hypochlorite diffuses more slowly than chlorine, and the speaker thinks that is true, then we should expect some organisms to get by. In our testing, out of every 100,000 gallons we are collecting a sample probably of 100 cc. and we need a larger number of samples perhaps in order that a fair test may be made. With the liquid chlorine, so far as our observations go, there are no after-growths to be found. It seems that the bacilli that remain afterward are of such a class that they do not rapidly increase in the distribution systems, and that that may be due in large part not only to the efficiency of the liquid chlorine itself, but to the superiority of its diffusion and the improved quality of the mix that one gets by using the chlorine solution as against the hypochlorite solution with its extreme variation in strength, even when the same material is used, as Mr. West has shown.

Mr. Francis D. West: In reply to that question the author would state that he had intended, at a later date, to take up the subject of the apparent difference between bleach and liquid chlorine as to the lasting effect on bacteria in water or, in other words, in relation to after-growths.

When using bleach we found an increase in the number of bacteria in the water in our mains; studies were made along certain pipe-lines. These studies showed that there was a gradual increase with increasing distance from the filter plant.

As there were other influences affecting the count, such as the existence of dual connections, it is quite possible that many of the increases were not caused by bacterial development.

Previous to the installation of the liquid chlorine plants, all these influences, with the exception of storage in open reservoirs, were removed. The following tables give the data for district samples for the months of April and May, 1914:

Torresdale filtered water basin

MONTH	BACTERIA PER CC.			B. COLI CUMMUNIS		
	Average	Maximum	Minimum	Tests	1 cc. +	10 cc. +
April	13	52	4	31	0	1
May	9*	34	3	31	0	3

* Omitting May 28–29 Filter Plant, shut down due to break at Lardner's Point Pumping Station.

DISTRICT SAMPLES

Averaging 19 sampling points and omitting two sources supplied through open reservoirs.

MONTH 1914	AVERAGE BACTERIA PER CC.			B. COLI COMMUNIS		
	Maximum	Minimum	General	Tests	1 cc. +	10 cc. +
April	45	9	15	222	1	3
May	32	6	13	218	2	8

The following table shows the results from eight sampling points, each a mile apart.

LOCATION	DISTANCE FROM TORRESDALE BASIN	BACTERIA PER CUBIC CENTIMETER					
		April			May		
		Max.	Min.	Aver-age	Max.	Min.	Aver-age
	miles						
5900 Torresdale Avenue	4	37	3	12	11	3	6
*Main and Foulkrod Streets	5	430	10	140	1800§	50	100
Erie Avenue East Frankford	6	63	5	15	13.	4	9
Front and Kensington	7	32	4	11	15	4	9
Beach and Poplar Streets	8	16	4	10	18	2	8
712 North 5th	9	27	3	9*	27	6	9
516 South Street	10	44	11	21	24	3	8
Pennsylvania Salt Works	11	24	8	12	17	5	12

* 5 miles direct 8½ miles by way of Wentz Farm (open reservoir).

§ Reservoir treated with copper sulphate.

B. coli 178 tests 1 cc. + = 1 10 cc. + = 4.

It will be seen that with the exception of the water coming from Wentz farm reservoir, which shows the development on storage due to algae growth, there is practically no difference between the sampling points. General averages of 15 and 13 compared with 13 and 9 show that no after-growths occur in the filtered water disinfected with liquid chlorine.

The action seems to be decidedly superior. My conclusion is that the action is more permanent with liquid chlorine than with chloride of lime.

Mr. Robert Spurr Weston: Mr. West very kindly placed this paper in the speaker's hands, and it has been read through with a great deal of interest. As he has described in detail the efficiency of the economical process which he is using at Torresdale, there is little which the speaker can add, except to approve of his use of liquid chlorine, even for so large an installation.

The experience at Exeter, New Hampshire, where experiments with both bleaching powder and liquid chlorine have been used, may be of interest, although they have not been completed. At this plant it was impossible to coagulate the water to a satisfactory degree by the use of sulphate of alumina alone. This was because of the low alkalinity of the reservoir water, and the fact that it is taken from an impounding reservoir, which about four years ago was enlarged by raising the dam, causing the flooding of a large area which is overgrown with vegetation. This vegetation impregnates the water with a kind of colloidal vegetable matter, resembling in its physical and chemical properties cucumber or quince seed juice more than anything else. When treated with the amounts of sulphate of alumina which could be used without increasing the alkalinity artificially (about 2 grains per gallon) and subjecting the water to a 4-hour period of coagulation, the color was reduced on an average from 80 to 20 parts per million, and it could not be reduced below 10 parts, even with the use of excessive amounts of sulphate of alumina and the necessary soda. Furthermore, the gelatinous vegetable matter collected in the sand not only made frequent washings of the filters necessary, but collecting at the surface made it imperative to remove the accumulation by scraping. This accumulation persisted in spite of the fact that the arrangements for washing the filters were improved.

Beginning last year bleach was added to the water in the proportion of 0.4 parts of available chlorine per million, and recently liquid chlorine has been used in its place. It was found that more work could be accomplished by using 0.4 parts of chlorine per million than by the use of 15 parts of sulphate of alumina.

At present 0.58 part of liquid chlorine per million is being added, and practically perfect results are being obtained, notwithstanding the fact that the water from the Exeter reservoir is one of the most difficult to treat which the speaker has encountered, for, besides the color and vegetable matter, the water at times contains considerable clay, washed from the banks of the reservoir by the waves during storms.

Comparing a sample collected for analysis in June, 1913, with one collected in June, 1914, the results shown in the following table were obtained.

The Association owes a great debt of gratitude to Mr. West for this admirable presentation of his work and for the very good résumé of the whole subject, concerning which information is not very generally diffused. The value of the paper will become more apparent as it is read, than during the limited time that Mr. West has had for its presentation.

Results of purification with and without the use of chlorine

	PARTS PER MILLION	
	June, 1913	June, 1914
Color, reservoir	90.0	75.0
Color, effluent	45.0	6.0
Turbidity, reservoir	15.0	18.0
Turbidity, effluent	4.0	1.0
Oxygen consumed, reservoir	9.40	7.52
Oxygen consumed, effluent	5.45	2.92
Alkalinity, reservoir	21.0	18.0
Alkalinity, effluent	13.0	9.0
Albuminoid ammonia, reservoir	0.308	0.304
Albuminoid ammonia, effluent	0.178	0.142
Iron, reservoir	0.65	0.45
Iron, effluent	0.40	0.08
Increase in chlorine	0.0	0.36
Chlorine added	0.0	0.50
Bacteria at 20°C., reservoir	350.0	148.0
Bacteria at 20°C., effluent	45.0	14.0
B. coli, reservoir	Positive	Negative
B. coli, effluent	Negative	Negative

Mr. J. Walter Ackerman: Mr. West wrote to the speaker in relation to what we were doing at Auburn. Unfortunately the speaker was not able to give him any particular results, for the reason that at the time we were applying the hypochlorite and we did not have the advantage of a bacteriologist on the job. We now have a bacteriologist employed constantly. In October of last year we began the application of liquid chlorine. Of course the speaker was very glad to know that Mr. West had had some of the difficulties of the application of hypochlorite that had been our experience; notably, our pump packings went to pieces, and of course stopped up the orifices of the tanks, and we were under some uncertainty as to whether the piping was not stopped up also. That is an experience common to all of us in that line. We are on perhaps the border line of the places that can afford to have all this apparatus and the smaller places, our daily use being a little over 6,000,000 gallons per day.

As to the matter of cost which has been mentioned so many times, is not the cost a comparatively small matter, that is the relative cost between one and the other, if you can get any better results from one than the other? The cost per million gallons is so small that it is practically negligible; and when you take into consideration the benefits that you get, the cost is so little that it should hardly be given consideration. The water which we have is an unfiltered raw water; and although it is from a lake of 10 square miles in area and our sedimentation under normal conditions is fair, our raw water running, excepting during the spring floods, under 100 bacteria per cubic centimeter, in the spring floods we sometimes get as high as 5000.

As to the after-growths, the speaker cannot say anything about them with hypochlorite, but does note a slight difference at the present time when we take our samples. If we take a sample immediately in the pump discharge we are apt to get a slightly higher count than in the city.

The author has well spoken of the labor connected with it. There is one thing he omitted to speak of, and that is when you use hypochlorite of lime you have an accumulation of empty cans that you do not know what to do with. This in our own case is quite a problem. We have a pumping station that is located out in the lake. One of our workmen decided that one of our old cans needed disposing of, and was told to dispose of it, because it was old and uncertain in content. So he dumped it into the creek, and it killed many fish. We paid $100 to the State Conservation Commission as a fine for killing the fish. But in general liquid chlorine has proved very satisfactory with us, and we would not want to go back to the hypochlorite of lime.

Mr. H. F. Huy (*by letter*): The writer has read Mr. West's paper with interest and he thinks it is very comprehensive. However, there are a few points on which he thinks Mr. West has misunderstood him in his previous explanation, as affecting the plant of the Western New York Water Company.

On page 442 where he states that the results are not comparable, due to the fact that we used liquid chlorine in the raw water and the sedimentation basin. The results we obtained were comparative due to the fact that, at that time, we were filtering 6,000,000 gallons of water daily and using 30 pounds of hypochlorite of lime in the effluent from the filters and obtaining satisfactory results. We obtained the same results in the same effluent by the use of 3 pounds of liquid chlorine. In both cases there was no liquid chlorine applied to the raw water. Therefore the results are comparable.

The question might be raised as to why the liquid chlorine was more effective than the hypochlorite of lime in a greater ratio than is warranted by the greater percentage of chlorine in the solution. This may be somewhat accounted for by the fact that when you mix the hypochlorite solution and use only 30 pounds per day, it is probable that a considerable amount of the hypochlorite of lime may not show even 25 per cent of chlorine, and that the hypochlorite of lime no doubt deteriorates very rapidly; especially after the can has been opened, and the sterilizing effect is reduced.

The tests that we made covered a period of at least two months; therefore we were able to determine this more from a practical than a theoretical view point.

Recently the writer has heard a considerable amount of criticism in regard to a taste in the water, claimed it to be caused by the use of hypochlorite of lime, especially in places where water is taken from the Great Lakes, such as Toronto, Cleveland, etc. We have periodically observed a taste in this water due to dead algae, which taste is somewhat similar but not nearly as nauseous or as brackish as that produced by the use of hypochlorite of lime; but the general public has attributed this taste, whenever noticeable, to the use of hypochlorite if same is used by private or municipal water works. The writer understands that this has especially caused considerable objection lately in Toronto. Our experience in Niagara Falls and Buffalo is that you cannot use more than 5 pounds of hypochlorite of lime in the water of the Great Lakes without noticing a taste therefrom in the treated water. Compared with this, we can use 5 pounds per million gallons of liquid chlorine, which is practically equivalent to about 40 pounds of hypochlorite of lime, before noticing a taste, and then the taste is not nearly as objectionable as that produced by the use of hypochlorite of lime.

For the last five months we have been treating the raw water of Lake Erie at our Buffalo plant, with 1 pound of liquid chlorine per million gallons. The bacteria count in the raw water at our pumping station, which is located about 3 miles south of the southerly city limits of Buffalo, and the intake of which is located about 1½ miles out in the lake, varies from 200 to 1200 per cubic centimeter with turbidity ranging from 0 to 100. This latter turbidity is only obtained during a few months in the year. Generally speaking the water is very clear. By treating this water with 1 pound of liquid chlorine per million gallons we are able to reduce the bacterial count to 20 per cubic centimeter with no indications of B. coli in 10 cc. sowings. Generally the raw water in the lake shows B. coli indications in 10 cc. sowings.

The writer is very sorry that Mr. West's paper does not show our results as compared with those of the municipal plant at Niagara Falls, as he thinks same should be included, for the reason that the water supply taken by the municipal plant is not taken from the shore, as is that taken by the water company, therefore its bacterial count in the raw water is generally about 2500, although there are B. coli indications in 1 cc. sowings. Their type of filter is a standard type of filter, but is ineffective in removing the B. coli or producing a count much below 200. To obtain a quality of water which competition with the private company has made them deliver, they have attempted to obtain results by the use of hypochlorite of lime, using as high as 4 pounds per million gallons, and at times in excess of this amount, and still not accomplishing as good a result as we do at the private company's plant. They also, very often, get a very noticeable taste in the water furnished to the consumer, and the municipal water works department has lately been subject to considerable criticism due to this trouble.

Mr. C. A. Jennings (*by letter*): Mr. West's paper is a very thorough and fair statement of any argument on "hypo vs. liquid chlorine." When the manufacturers first made their claims that 1 pound of liquid chlorine would do the work of from 4 to 6 pounds of hypo, the writer was skeptical and thought that these were merely talking points for the salesmen. Judging from the experiences at Philadelphia and elsewhere with liquid chlorine after having had experience and data on hypo, it would seem that if anything these statements were really conservative.

The writer has seen a number of liquid chlorine installations and has been impressed with their simplicity and compactness. Some time ago he spent several months experimenting at the Bubbly Creek filter plant at the Chicago Stock Yards trying to find a suitable regulating valve for liquid chlorine. The problem was a hard one.

The automobile has replaced the horse for many purposes but has not eliminated the horse. The writer feels that liquid chlorine will supplant hypo in many plants now using hypo, and that it will be installed in a large number of cities, not now using any disinfectant, in preference to hypo. However, he does not believe that hypo will be eliminated. It will probably be used for smaller installations, because of the smaller installation cost for the small and medium sized plants, and will be used to quite an extent for sewage, where the odor from the drums and the turbid solution will not be objectionable. He does not believe that all of the drawbacks laid to hypo are correctly placed. Many of the troubles laid to the use of hypo are really due to lack of attention; faulty design of the treatment plant; incomplete mixing of the solution; expecting from the use of hypo a greater removal of bacteria than is really practicable or necessary, and the adjustment of the dose to obtain this maximum removal.

MR. GEORGE A. JOHNSON (*by letter*): The writer has read Mr. West's instructive paper with great interest. Hypochlorite of lime will continue to be used in a large number of places, of course, but there seems to be no question that as a general proposition the liquid chlorine process is the better.

Briefly speaking, the advantages of the liquid chlorine process are not in the line of reduced cost, as compared with the hypochlorite of lime process, but in ease and convenience of application. The chemical is pure and concentrated in small containers, whereas hypochlorite of lime is bulky, varies greatly in its content of "available chlorine," and is troublesome to handle. The latter deteriorates in strength as soon as the containers are opened, whereas liquid chlorine in iron containers holds its original strength almost indefinitely. The space required for a liquid chlorine apparatus is exceedingly small as compared with the space required for storage of the dry chemical, and mixing and storage tanks for the solutions.

The writer is a believer in liquid chlorine, and thinks that the author has well stated the case in the closing paragraph of his paper:

> While in some instances liquid chlorine may prove more costly than chloride of lime, the regularity with which it can be applied, the more effective the action on pathogenic bacteria, the small, compact apparatus, and the absence of the odor of chlorine around the plant, recommend it as a satisfactory substitute for hypochlorite, having as it does all the advantages of the latter and only some of its faults.

MR. GEORGE C. WHIPPLE (*by letter*): Mr. West has given us a valuable contribution to the literature on water disinfection by the use of chlorine. Particularly interesting are the data as to the relative cost of disinfection with calcium hypochlorite and liquid chlorine. It would be a convenience for those who desire to study the subject further if the author would arrange the cost of the two processes in tabular form in some such unit as dollars per million gallons. As given in the paper it is a little hard to make the comparison.

It seems evident that both calcium hypochlorite and liquid chlorine may be relied upon to disinfect water supplies, and that the two processes are about on a par as to the efficiency and freedom from tastes and odors, provided that both chemicals are added to the water in proper amounts and with proper regularity. The advantages of liquid chlorine over calcium hypochlorite appear to lie in the field of economy and convenience. It is not clear that in all cases liquid chlorine is cheaper. Both chemicals probably have their special adaptations and with time these will become defined.